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GPS-IR for accurate tide gauge measurement at South Beach, Oregon, United States

Kutubuddin Ansari[*1], **Tae-Suk Bae** [1]

[1]Department of Geoinformation Engineering, Sejong University, Seoul 05006, Korea

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ABSTRACT

Global positioning system-Interferometric Reflectometry (GPS-IR) method is applied to measure the sea level measurement by utilizing the geodetic quality of GPS receiver for detecting the adjacent ecosystem, including the advantages of climate related or non-related sea level information. The comparative analysis of tide gauge (TG) measurement interpretations collaborates with an essential role for nowcasting and forecasting variability within the selected region. In recent years, Auto-Regressive Moving Average (ARMA) and Singular Spectrum Analysis (SSA) have been showed to be the strong techniques providing a comparatively perfect estimation in time-series evaluation comparable to the fashionable methods. In the current study, GPS derived TG (GPS-TG) records from the station named SEPT (44.63 ^{0}N, 124.05 ^{0}W) located at South Beach, Oregon, USA are predicted with the ARMA (ARMA-TG) and SSA (SSA-TG) methods. The analysis demonstrates that the GPS-TG is correlated with SSA-TG about 99.8% and has a correlation of about 98.1% with ARMA-TG predicted values. We believe the methodology applied in the current study will contribute to the numerical modeling of TG records as well as other studies related to the reflectometry techniques.

1. INTRODUCTION

Global positioning system (GPS) is the modern systems in the field of geodesy frequently used for multiple purposes such as crustal deformation, coordinate transformation, ionosphere, troposphere, positioning, surveying etc (Ansari 2014; Akala et al 2015; Alshawaf et al 2016; Mukul et al 2014; 2018; Ansari et al 2018). The Global Positioning System-Interferometric Reflectometry (GPS-IR) technique has been established and proved for measuring sea-level measurements, storm signature tide records, inland water, flooding inundation, tsunamis, surface soil moisture, snow depth, and vegetation water content (Vey et al 2016; Tabibi et al 2020). Several studies have been agreed that a single geodetic receiver is capable to deliver comparable accuracy of such type measurement, which includes traditional tide gauges (TG) (Larson et al 2013; Ansari et al 2020). The design of GPS antenna is arranged in such a way that the receiver can receives both direct signal (Right-Handed Circularly Polarized or RHCP), and the reflected signal (Left-Handed Circularly Polarized or LHCP) as shown in Fig. 1. The strength of GPS signal which includes phase and code observations is measured as signal-to-noise ratio (SNR) from the RINEX observable data. The unit of SNR measurement is measured in decibel (dB) or decibel-Hertz (dB-Hz) implies the power ratio to the measured noise of the GPS signals. In the current study we used seasonal SNR measurements of GPS station located at South Beach, Oregon, United States and analyzed the tide gauge analysis by taking advantages of global forecasting Auto-Regressive Moving Average (ARMA) and Singular Spectrum Analysis (SSA) models. The summary of mathematical equations can be found in Section 2, data description in Section 3, result and discussion in Section 4 and finally conclusion in Section 5.

2. METHOD

The studies related to GPS-IR usually based on the multipath mitigation, or obstruction of direct and reflected signals from surface object. The oscillation waves of reflected signal directly influence the signal strength (SNR measurement). The mathematical formulation such wave signal is given by most equations as follows (Roesler and Larson 2018; Peng et al 2019):

$$SNR = A\cos\left(\frac{4\pi}{\lambda}H_0 \sin\theta + \phi\right) \tag{1}$$

* **Corresponding Author**

*(kdansarix@gmail.com) ORCID ID 0000-0002-6151-6241
(baezae@sejong.ac.kr) ORCID ID 0000-0002-7537-8732

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where A denotes the amplitude for the function deviation from zero (in meter), ϕ is called the phase (in radians). H_0 is reflector height (meter), λ is wavelength (meter) and θ is elevation angle (degree). Axelrad et al. (2005) approved that if we take f_M as a spatial frequency multipath measurement that cycles per full satellite arc from 0 to 90° then it can be easily estimated by using following formula:

$$f_M = \frac{2H_0}{\lambda} \quad (2)$$

The SNR attained values from Eq (1) is utilized to calculate the f_M by applying Lomb-Scargle periodogram (LSP) (Press et al 1996), which is called the dominant frequency ($f_{m,t}$). Then the simple planar reflector distance can be transferred like to an effective reflector height (H_{eff}) following the Eq. (2) (Larson et al 2013).

$$f_{m,t} = \frac{2H_{eff}}{\lambda} \quad or \; H_{eff} = \frac{1}{2} f_{m,t} \lambda \quad (3)$$

Here the unit dominant frequency ($f_{m,t}$) is dimensionless, later the wavelength (meter) multiplication to the reflector height (H_{eff}), it will transform in meter (meter).

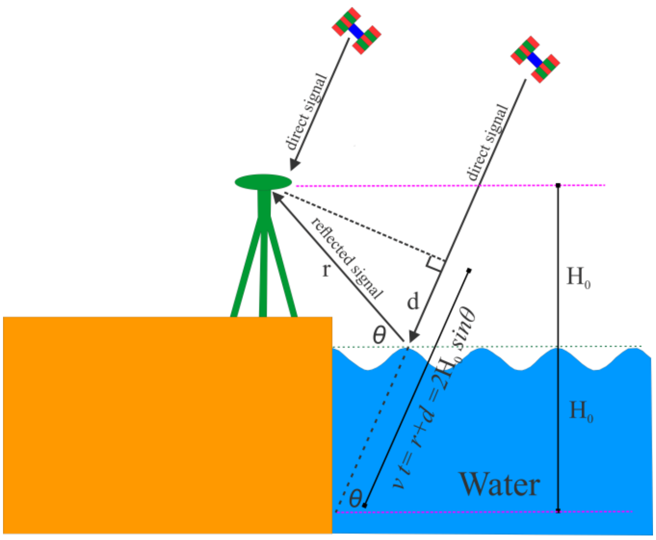

Figure 1. GPS-IR technique where the GPS antenna is arranged in such a way that the receiver can receives both direct signal (Right-Handed Circularly Polarized or RHCP), and the reflected signal (Left-Handed Circularly Polarized or LHCP)

3. DATA

The study investigates TG record estimation (GPS-TG) by exploiting the SNR data measurement from GPS station located at South Beach, Oregon, United States with the geographical coordinates of (44.63^{0}N, 124.05^{0}W). Global forecasting models such as Auto-regressive Moving Average (ARMA) and Singular Spectrum Analysis (SSA) are used for the current study. The GPS antenna elevation height is measured -16.5564 m in ITRF14 reference frame. The GPS station consists of choke-ring zenith pointing antenna TRM29659.00 have standard geodetic quality. A dual frequency of receiver with carrier-phase named ASTERX-U with 1 Hz frequency was applied during the data collection. The marker name of GPS site was named SEPT (Fig. 2). There were very high strength GPS signals available in USA, hence in the current study only GPS satellites L-Band dual frequency signals with wavelength of 19.05 cm (for L1 signal) and 24.45 cm (for L2 signal). Later we compared the results of GPS-TG records with the nearest National Water Level Observation Network (NWLON) sentinel station (Station ID: 9435380) for the purpose of validation.

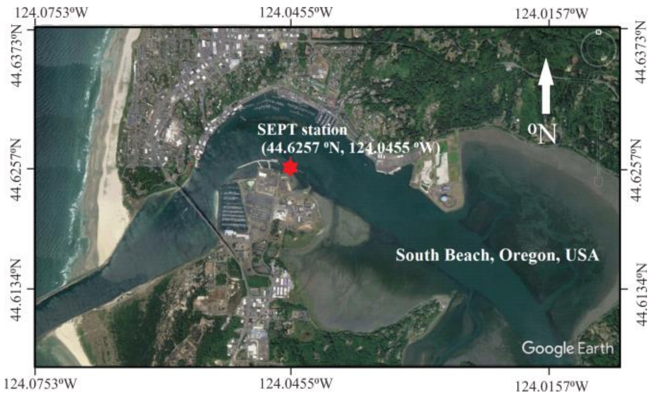

Figure 2. GPS station location geographical coordinate of 44.6257 ^{0}N, 124.0455 ^{0}W (with red star and marker name SEPT) at South Beach, Oregon, USA. The station consists of choke-ring zenith pointing antenna TRM29659.00 (Trimble Inc.) and dual-frequency carrier-phase GNSS ASTERX-U receiver.

4. RESULT AND DISCUSSION

The data was collected by considering of seasonal variation for the year and found the best recorded dates like this: for spring season on 04 April 2017, for summer season on 10 August 2017, for autumn season on 10 October 2017 and for winter season on 01 January 2018. Each epoch satellites data (both L1 and L2 signals) are processed and compared the NWLON secondly data to handle the estimated errors. In this way, it was very easy to exclude the records which have high difference from each other. Relative difference between GPS-TG and corresponding NWLON-TG is visible in Fig. 3. There were few circles (GPS-TG) well matched with dash lines (NWLON-TG) and few of them are overestimating and underestimating. Only the point which have positive values are selected because the model does not consider negative value, then correlation coefficient (CC) and root mean square (RMS) between GPS-TG and NWLON-TG are estimated as shown in Table 1. Results shows that GPS-TG and NWLON-TG are correlated with the CC of 0.942 and RMS of 12.90 cm. These GPS-TG records forecasted with ARMA model and obtained results also have been shown in Table 1. Now if we look at the table the GPS-TG and ARMA-TG records are correlated with CC of 0.981 and RMS of 4.80 cm. This correlation and RMS are better than NWLON-TG, hence we can conclude that ARMA model results perfectly estimated measured GPS-TG and indicates the applicability in the field of reflectometry.

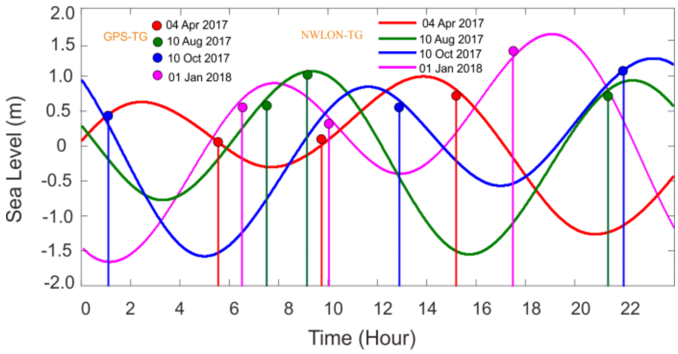

Figure 3. Three points per day GPS-TG records in seasonal dates with dotted points and vertical lines. NWLON-TG data is represented by horizontal lines. Best recoded GPS-TG dates are distributed like this: for spring season on 04 April 2017, for summer season on 10 August 2017, for autumn season on 10 October 2017 and for winter season on 01 January 2018.

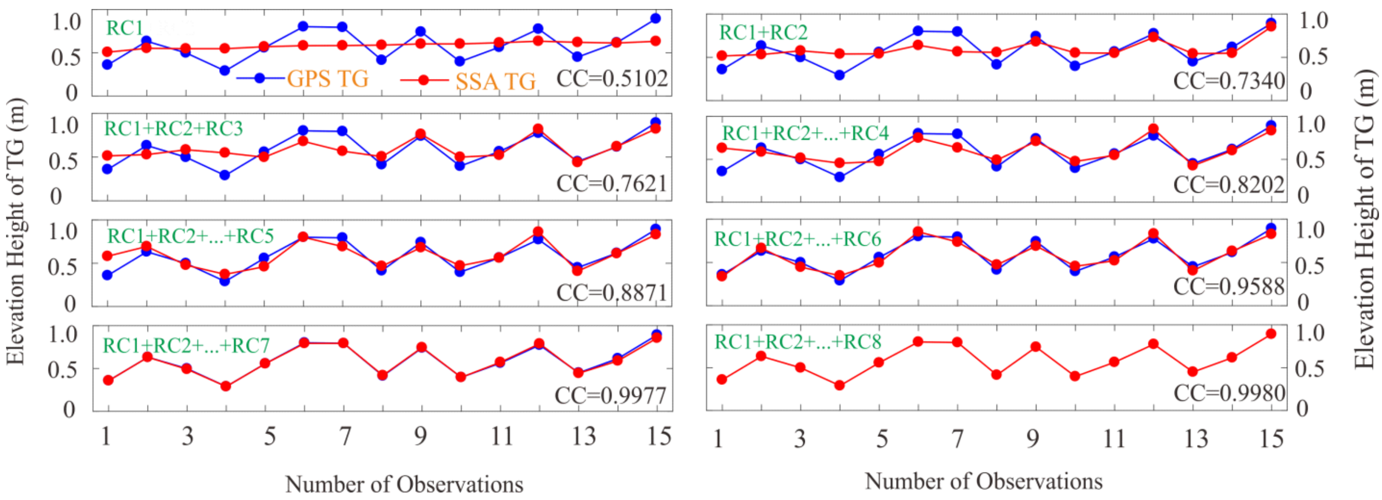

Figure 4. GPS tide gauge (GPS-TG) plot on selected seasonal days with Singular Spectrum Analysis reconstruction of tide gauge (SSA-TG) time-series. The correlation coefficient (CC) of each set have been given in respctive column.

Table 1. Tide gauge (TG) observation comparisons

Predicted vs Observed TG	(CC)	RMS (cm)
NWLON-TG vs GPS-TG	0.942	12.90
ARMA-TG vs GPS-TG	0.981	4.80
SSA-TG vs GPS-TG	0.998	0.88

In the paragraph above we discussed the comparative analysis of NWLON-TG vs GPS-TG and ARMA-TG vs GPS-TG and found that ARMA model better estimates TG records. Now we forecasted GPS-TG with SSA-TG by taking window length of eight and examined the CC of reconstructed components (RC) from beginning to the end. The CC between RC (SSA-TG) and GPS-TG has been shown in Fig. 4. As we can see from figure that first RC showed that the observed GPS-TG and first RC (RC1) are correlated with the CC of 0.5102, which means they have 51.02% relationship with each other. Now the second RC (RC2) is added in RC1 and the CC of each other (GPS-TG vs RC2-TG) again checked, that has been found to be equal to 0.7340. This indicates that RC1+RC2 estimated TG and GPS-TG have 73.40% relationship. Similarly, third and fourth RCs are added and then the CC between RCs-TG and GPS-TG are checked. It has been noticed that CC of RC1+RC2+RC3 and RC1+RC2+ RC3+RC4 improved till 76.21% and 82.02% respectively. This means that RC3 and RC4 support improving correlation of 2.81% and 5.81% respectively. Finally, all RCs (RC1+RC2+...+RC8) are added and it has been noticed that CC increase continuously and reached up to approximately 0.998, means SSA-TG and GPS-TG have almost one to one relationship. The scientific explanation of each RC components can be found in our journal paper (see Ansari et al 2020). If we look at the Table 1, the results showed that GPS-TG and SSA-TG are correlated with the CC of 0.998 and RMS of 0.88 cm. This correlation and RMS are better than both NWLON-TG and ARMA-TG. Hence in support to the SSA we can conclude that SSA is best forecasting tool and successfully able to forecast the TG records.

5. CONCLUSION

The study investigates SNR observation from GPS station located at (44.6257 ^{0}N, 124.0455 ^{0}W) South Beach, Oregon, USA by collected seasonal data. GPS-TG were estimated during the study and the results are compared with NWLON sentinel station with ID: number of 9435380 for the purpose of validation. Results showed that GPS-TG and NWLON-TG are correlated with correlation coefficient (CC) of 0.942 and root mean square (RMS) of approximately 12.90 cm. Later these GPS-TG data is predicted the global model know as Auto-regressive Moving Average (ARMA) and Singular Spectrum Analysis (SSA) methods. Results showed that GPS-TG and ARMA-TG are correlated with the CC of 0.981 and RMS of approximately 4.80 cm while GPS-TG and SSA-TG are correlated with CC of 0.998 and RMS of approximately 0.88 cm. Hence, we can conclude that SSA is the best forecasting tool and successfully able to forecast the TG records.

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